Stratigraphic Palynology of the Murray River Valley in New South Wales

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HELENE A. MARTIN. Stratigraphic Palynology of the Murray River Valley in New South Wales. *Proc. Linn. Soc. N.S.W.* 115: 193-212 (1995)

The Murray River region, from Cohuna to Albury, has a complex stratigraphy which has a bearing on groundwater quality. The basement is Palaeozoic, Early Permian and Mid Permian in age, and the last-named is confined to the Oaklands-Coorabin coalfields. The Cainozoic sediments range from the late Eocene, the oldest, found in the west of the study area, to Pleistocene, the youngest, in the east. Low salinity groundwater is found in the Tertiary sands and gravels.

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KEYWORDS: Murray Basin, Murray Valley, Permian, Cainozoic, palynostratigraphy

INTRODUCTION

The Murray River system can be traced back to Eocene time, at least 50 million years. Most of the major tributaries have existed from Eocene time also (Stephenson and Brown, 1989). The position of the mouth of the Murray River has been controversial. One school of thought proposes that the river extended across the present line of the Mt. Lofty Ranges before these ranges were uplifted, along what is now the course of the Broughton River and emptied into Spencers Gulf (Williams and Goode, 1978). The other school of thought claims that the outlet of the Murray River has always been east of the Mt. Lofty Ranges (Stephenson and Brown, 1989), although the location of the mouth was variable and intimately associated with the marine transgressions of the Murray Basin. For a fascinating account of river history and this controversy, see Stephenson and Brown (1989).

The upstream, non marine part of the Murray River has a similar long history. A study of the pre-Tertiary basement contours under the southern Riverina Plain in Victoria (Macumber, 1978) suggest that a drainage system ancestral to the Murray River was in existence in Eocene time. From Oligocene to early Miocene time, it is not possible to demonstrate the presence of a co-ordinated drainage system because the Murray River Valley was then probably little more than a swamp. In late Miocene times, a co-ordinated system re-appeared, and the palaeo-Murray flowed into a deep marine embayment in the vicinity of Cohuna (Macumber, 1978).

The study area (Fig. 1) extends along the river from the southeastern edge of the Murray Basin near Cohuna and Wakool in the west, to Albury and Holbrook in the east. The deeper sediments in the west become shallower with distance upstream. The deepest, oldest Tertiary sediments are late Eocene and the shallowest, at the eastern end of the study area, are late Pliocene-Pleistocene.

Tertiary sediments form the cover beds of the Permian Oaklands - Coorabin coal basin. Coal was mined from 1917 to 1920, when production ceased because of water problems. Intermittent production of coal continued from 1934 to 1958, and the colliery closed in 1959 (Bembrick, 1975). There is recent interest in these coal deposits, but reopening the mines would raise serious environmental issues as the mine waters have a high salt content.

The valley sediments are important for groundwater. Interest in groundwater

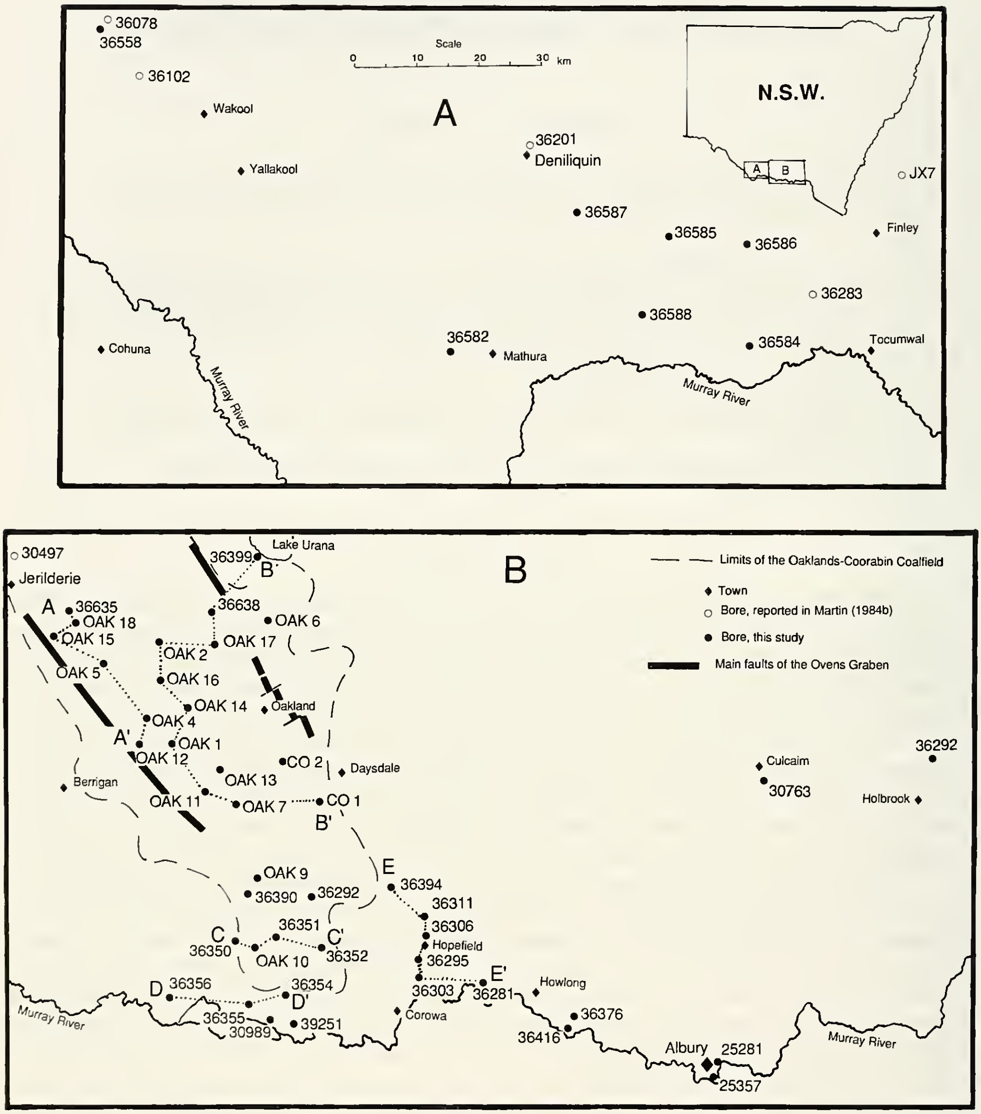

Fig. 1. Locality map. The limits of the Oaklands - Coorabin Coalfields are from Bembrick (1975).

began before the turn of the century when gold mining encountered water in the auriferous 'deep leads' in Tertiary sands. As the area became more populated and settled, bores were drilled to the upper aquifers for stock and domestic water supplies (Williams, 1989).

This paper reports the stratigraphic palynology of the Tertiary sediments and Permian basement. Bores sunk for exploration of the coal fields have been resampled and the results are reported here also.

Materials and Methods

Both core and cutting samples have been used in this study. The possibility of contamination is greater with cuttings, both from carry down with the circulating mud and from cavings, but with proper drilling and sampling procedures, reliable samples may be obtained. For investigative drilling, the mud is circulated until it is clean of the coarse fraction and this practice greatly reduces contamination. If there is contamination it can be detected, either in the sediments themselves or in the preparations. A number of bores penetrate both Tertiary and Permian sediments and the amount of Tertiary contamination in the Permian may be assessed. Usually there is no or very little contamination unless sampling has occurred close to the contact. Barren samples may occur anywhere in the sequence and this would not be possible with appreciable contamination. While the possibility of contamination can not be ruled out completely, cuttings produce consistent patterns repeated in bore after bore, and this consistency would not be possible with appreciable contamination. There is thus reasonable confidence that these samples produce reliable results (Martin, 1984a).

Preparation techniques used hydrochloric and hydrofluoric acids to remove the mineral material, controlled oxidation with cold Schultz solution, and potassium carbonate to clear the residues. The residues were mounted in glycerine jelly.

Bores with five digit numbers are those sunk by the New South Wales Department of Water Resources. Bores sunk in the course of coalfield exploration are prefixed Oaklands (Oak) or Coorabin (Coo).

Geology

The basement in the eastern region consists of the lower-mid Palaeozoic Lachlan Fold Belt. These rocks are intensely folded, faulted and partly metamorphosed. Extensive but discontinuous Early Permian glacio-marine deposits form a thin veneer over much of this region. In the southern part, the glacial mud flows and tills suggest a close proximity to a glaciated land mass to the south (Brown, 1985; Brown and Stephenson, 1986).

In the Oaklands-Coorabin Basin, the Early Permian is disconformably overlain by the three fluvial sequences of the Late Permian Coorabin Coal Measures (Brown,1985). The dominant structural feature in the area is the Ovens Valley Graben, a northwest-southeast trending structure thought to have commenced subsidence in the Early Permian. The Early Permian sediments are found both in and out of the graben, but they are thicker in the graben. The Late Permian sequence is confined to the graben (Yoo, 1982), and are disconformably overlain by a mid Triassic unit (Morgan 1977).

The oldest Tertiary unit in this region is the late Eocene to ? mid Miocene Olney Formation that was deposited in fluvio-lacustrine, meandering-channel and extensive flood plan environments. It consists of grey coloured sands, silts and clays, which are frequently carbonaceous, and peaty coals (Brown and Stephenson, 1986). Wood is frequently encountered in the bores. The Olney Formation is found in the western part of the study area.

The Olney Formation is unconformably overlain by the Lachlan Formation that is equivalent to the Calivil Formation, and is late Miocene to Pliocene age (Williams, 1989). In the valley and where the pre-Tertiary basement is shallow, the Lachlan Formation overlies basement rocks. The sands and gravels of the Lachlan Formation consist mainly of quartz, and the clays are predominantly grey. There are minor carbonaceous clays. The upper part of the Olney Formation and the lower part of the Lachlan Formation may be difficult to distinguish apart on the evidence of lithologies alone.

Marine regression in the mid-late Miocene caused entrenchment of the drainage system as well as subaerial weathering that produced the distinctive Mologa Surface (Macumber, 1978). Transgression during the late Miocene caused sediments to be

deposited further and further into the highland river tracts, thus increasing the alluvial fill in the valleys. This static reworking of incoming sediments may have contributed to the concentration of gold in some of the sands and gravels forming the 'deep leads' (Williams, 1989).

The Shepparton Formation overlies the Lachlan Formation and is Pliocene in age (Brown and Stephenson, 1986). The lithology varies widely between the extremes of clay and gravel. The sands are quartzose, with only the upper part containing rock fragments representative of the present catchment rocks. The Formation is characteristically brown and yellow in colour. This Formation reflects a change in river morphology and possibly in climate. It has been deposited by leveed streams which meander within the alluvial zone, causing a build up of sediments. There are soil horizons at intervals (Williams, 1989).

The Quaternary Coonambidgal Formation (Brown and Stephenson, 1989) has inset terraces, rather than being topographically higher than the underlying Shepparton Formation. The streams of this time carried relatively low annual discharges, though the discharge could be relatively high during flood events (Williams, 1989).

The main aquifers are the quartz sands in the Lachlan Formation which yield low salinity water (Williams, 1989).

PALYNOSTRATIGRAPHY

Appendix 1 presents the palynological zones and ages assigned to the bores of this study.

Permian

The spores and pollen identified in selected samples are presented in Appendix 2 and the ranges of diagnostic species are shown in Fig. 2. Where specific diagnostic species are lacking, the assemblage may be assigned to the Early or mid Permian on general characteristics. For example, monosaccates (*Barakarites*, *Plicatipollenites* and *Potonieisporites*) and striated bisaccates (*Protohaploxypinus* and *Striatopodocarpidites*) are found throughout the sequence, but the monosaccates are abundant and bisaccates uncommon in the Early Permian, whereas the monosaccates are infrequent and the striated bisaccates (e.g., *Protohaploxypinus, Striapodocarpidites*) more common in the Mid Permian. Earlier studies of Permian palynostratigraphy place the upper part of the sequence in the Late Permian. Price (1983), reviews the history of Permian palynostratigraphy and places the upper part of the sequence in the Middle Permian. This study follows Price (1983).

The oldest assemblages are stage 3a, Early Permian, and the youngest, upper stage 5b (see Appendix 1). Figs. 3 and 4 present two cross sections through the Oaklands-Coorabin Basin.

Cainozoic

The palynology on numerous bores in the eastern non marine section of the basin correlates reasonably well with the zonation of Stover and Partridge (1973, 1982), constructed for the Gippsland Basin. There is one exception: the Upper *N. asperus* Zone, of latest Eocene-earliest Oligocene in the Gippsland Basin is not recognisable here by its original diagnosis. In the Murray Basin, the Late Eocene Middle *N. asperus* Zone is succeeded by the Oligocene *P. tuberculatus* Zone. The thick sections of the Oligocene-Early Miocene *P. tuberculatus* Zone may be subdivided using several quantitative events which have proved useful for correlation, at least on a local scale (Martin, 1984a; 1984b; 1984c).

The late Miocene-Pleistocene palynostratigraphy follows Martin (1987). Fig. 5 presents the palynostatigraphy of the Cainozoic and Appendices 3 and 4, the spores and pollen identified in selected bores.

Middle *N. asperus* Zone, late Eocene

Nothofagus spp. are abundant, and most of the pollen is the *brassii* type. Gymnosperms may be equally or more abundant at some levels, particularly *Phyllocladidites mawsonii* (see Appendix 3). Species whose ranges terminate at the top of the Middle *N. asperus* Zone, viz. *Proteacidites leightonii, P. reticulatus* and *Triorites magnificus*, are found here. The last named is restricted to the Middle *N. asperus* Zone (Stover and Partridge, 1973; 1982).

P. tuberculatus Zone, Oligocene-early Miocene

Nothofagus spp. are abundant, similar to the Middle *N. asperus* Zone, but the diversity of species is lower and the diagnostic species of the latter are not present. The *P. tuberculatus* Zone is divided into three parts, viz, the A subdivision, with a greater abundance of *Phyllocladidites mawsonii* and/or *Nothofagidites flemingii* (early Oligocene); the B subdivision, lacking the diagnostic features of the A and C subdivisions (mid-late Oligocene); and the C subdivision with the upper *Nothofagidites flemingii* acme and/or an increase in the Myrtaceae content so that it almost equals or exceeds *Nothofagus* spp. (latest

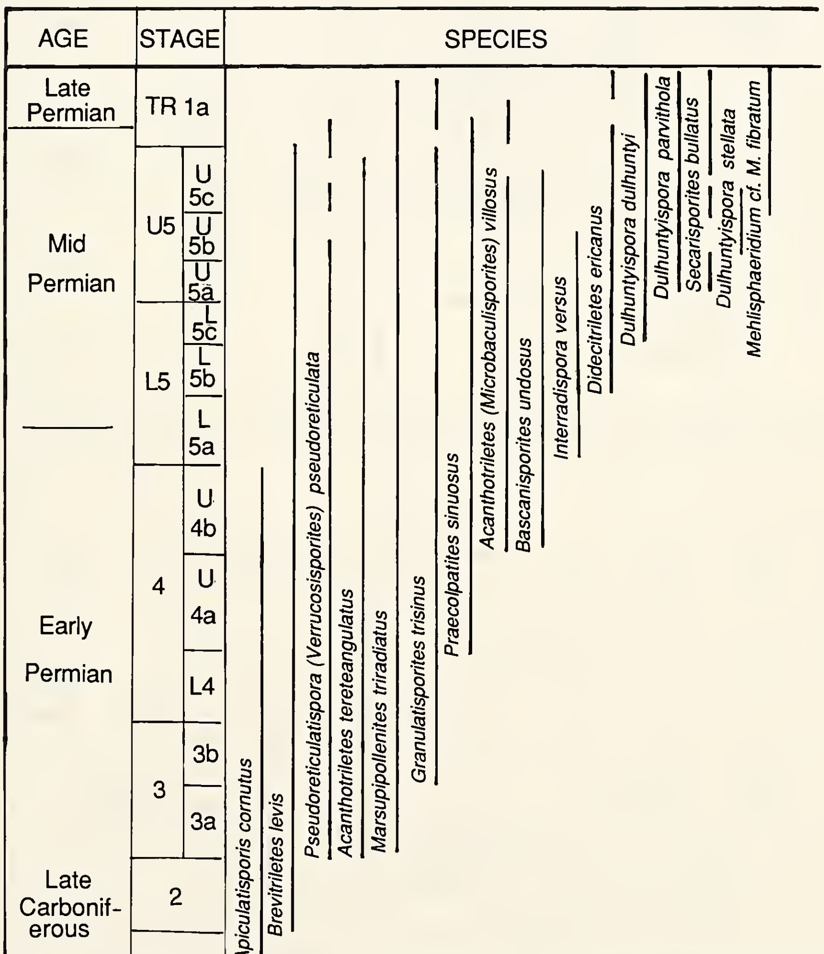

Fig. 2. Ranges of Permian diagnostic species, from Price (1983), Kemp *et al.,* (1977) and McMinn (1985). L, lower. U, upper.

Oligocene-early Miocene age) (Martin, 1984a; 1984b).

P. tuberculatus Zone, A subdivision, early Oligocene

Phyllocladidites mawsonii is abundant and in this respect, these assemblages resemble the Middle *N. asperus* Zone, but they lack the diagnostic species of the latter. *Nothofagidites flemingii* may be unusually abundant (the lower *N. flemingii* acme).

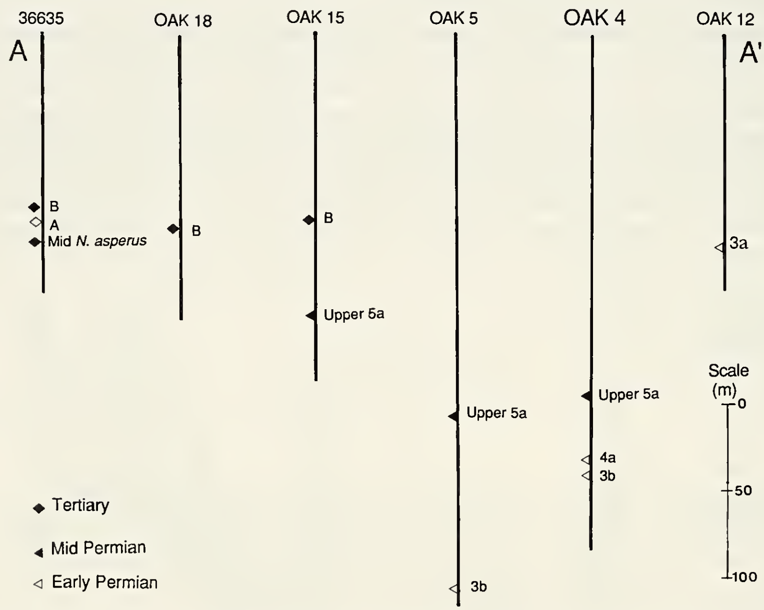

Fig. 3. Section A-A[1] through the Oaklands — Coorabin Basin. For the location of the section, see Fig. 1.

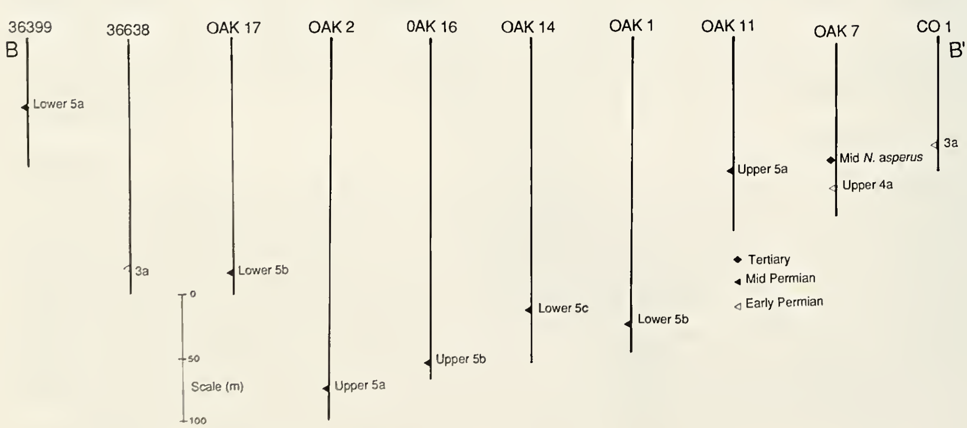

Fig. 4. Section B-B[1] through the Oaklands — Coorabin Basin. For the location of the section, see Fig. 1.

P. tuberculatus Zone, B subdivision, mid-late Oligocene

These assemblages lack the diagnostic features of both the A and C subdivisions. The *Nothofagus brassii* type is very common. Occasionally *Haloragacidites harrisii* (Casuarinaceae) is abundant as well.

P. tuberculatus Zone, C subdivision, early Miocene

Acacia first appears in the Early Miocene (Stover and Partridge, 1973), and although it may be found in earlier sediments elsewhere, it defines the base of this subdivision in this study area. The Myrtaceae/*Nothofagus* ratios below this level are low, and above it, may be high. The upper *N. flemingii* acme, if present, is concurrent with the increase in Myrtaceae.

T. bellus Zone, latest early Miocene-?late Miocene

Nothofagus, Myrtaceae or gymnosperms may be the most abundant group. The diagnostic species *Symplocoipollenites austellus* (*Symplocos*) and *Triporopollenites bellus* (*Gardinia* = '*Randia*' *chartacea* type) define the base of the zone.

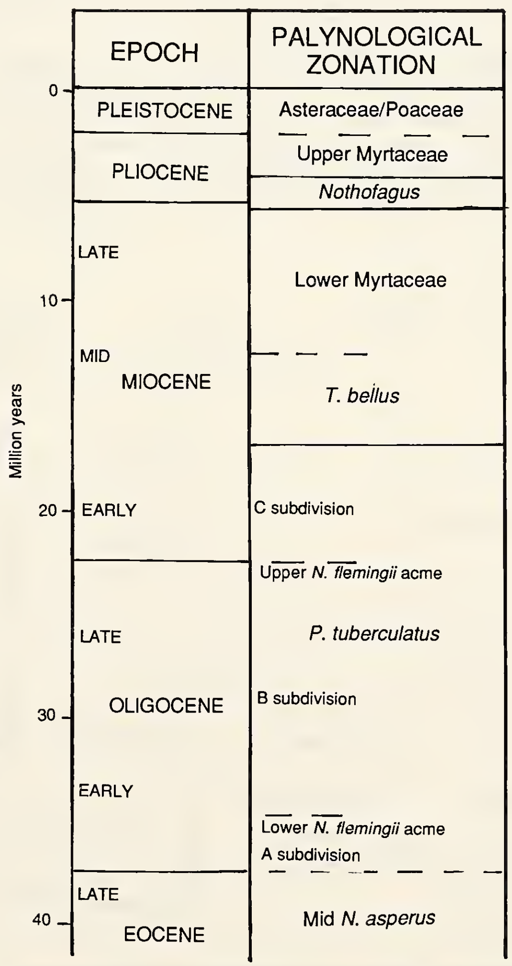

Fig. 5. Cainozoic palynostratigraphic scheme, from Stover and Partridge (1973) and Martin (1987).

The lower Myrtaceae phase, late Miocene

Myrtaceae and/or Casuarinaceae are the most abundant taxa, *Nothofagus* is absent, but the gymnosperms and some rainforest angiosperms are present. The Murray River Valley is similar to the Lachlan River Valley (Martin, 1987) in this respect.

The *Nothofagus* phase, ? early Pliocene.

Some *Nothofagus* is present, but only the *menziesii* and *fusca* types. The *Nothofagus brassii* type is absent. Gymnosperms may be unusually abundant.

The upper Myrtaceae phase, ?mid-late Pliocene.

This phase is essentially similar to the lower Myrtaceae phase. If the *Nothofagus* phase cannot be identified, then the upper and lower Myrtaceae phases cannot be distinguished apart.

Asteraceae-Poaceae floras, Pleistocene

Asteraceae and/or Poaceae increase substantially. In the river valleys of the western slopes and Lake George in the eastern highlands, Asteraceae is usually more abundant than Poaceae. There are very few gymnosperms and the rainforest element is absent or very reduced.

Polyporina granulata and *Tubulifloridites pleistocenicus* are frequently present in the Asteraceae-Poaceae floras. In this study, *P. granulata* is also found in the upper Myrtaceae phase and *T. pleistocenicus* has not been recorded (Appendix 4).

Figs. 6-8 present cross sections through the late Cainozoic sequence and Fig. 9, a pollen diagram. In this study, the *Nothofagus* phase is more diffuse and less of the discrete horizon than in the Lachlan River Valley (Martin, 1987).

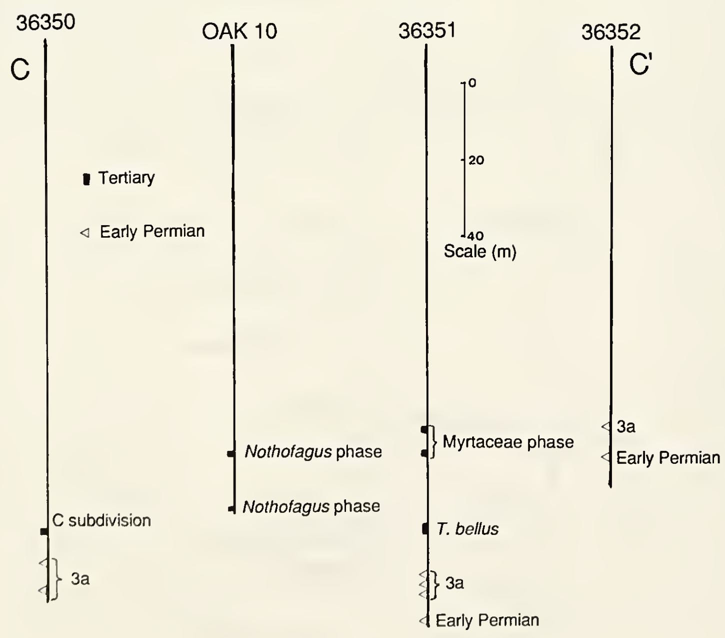

Fig. 6. Cross section C-C[1] through the Cainozoic sediments. For location see Fig. 1.

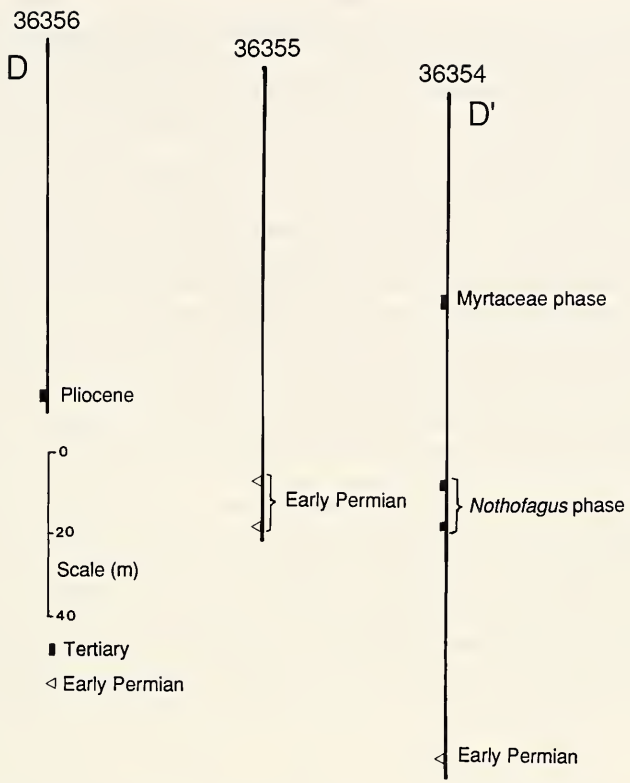

Fig. 7. Cross section D-D[1], near Mulwala. For location, see Fig. 1

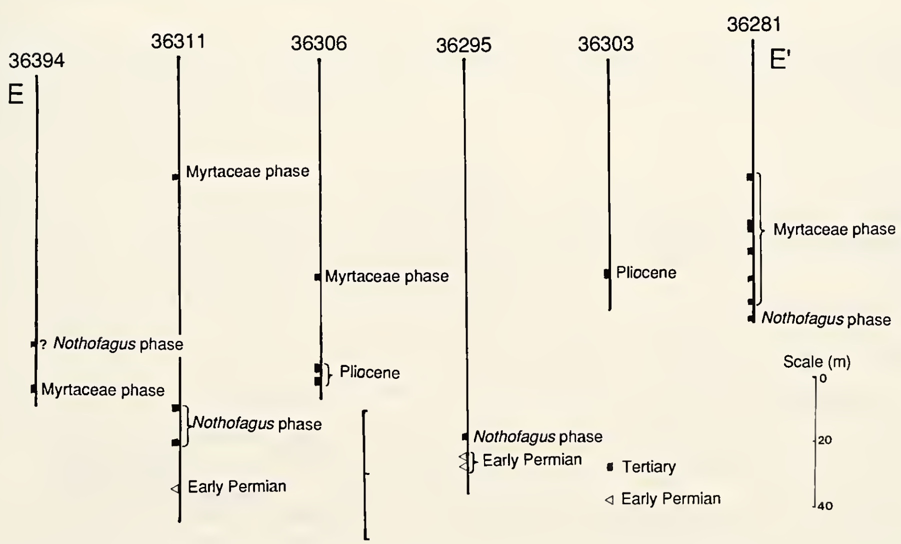

Fig. 8. Cross section E-E[1], through Hopefield. For location, see Fig. 1. Where there is insufficient evidence for a zone or age determination, an approximation of the age is based on general characteristics of the assemblages.

Discussion

The palynology shows a complex stratigraphy in the Murray River Valley. The Early Permian basement may be as shallow as 63 m, and the Tertiary sediments may be as deep as 260 m. The stratigraphy is extremely important to groundwater quality. Low salinity waters are only found in the Tertiary sands and gravels. Water in the basement strata has higher salinities.

The Permian sequence recorded here is in general agreement with previous reports. Triassic palynofloras previously reported by Morgan (1977) have not been found and samples from sediments thought to be Triassic in age proved barren.

The Eocene to Miocene sequence is similar to that found elsewhere in the Murray Basin. The vegetation of this time was 'semi-swamp' forest, similar to that of the lowland flood plains of New Zealand (Cockayne, 1958). The lowlands on the flood plains were subjected to prolonged flooding. Pools of water were frequent, but patches of dry ground were always present. Much of the ground was saturated for long periods and thick peat was common. Most likely, *Nothofagus* grew on the dry ground and the gymnosperms, especially *Dacrycarpus* and *Lagarostrobus*, grew in the swamps (Martin, 1993).

The most easterly occurrence of the early-mid Miocene strata are found in Bores 36350 and 36351 (Fig. 6). These bores are some 10-15 km north of the Murray River and indicate that the course of the river at that time was to the north of the present river.

Where evidence exists, it shows a widespread hiatus in the late Miocene (Martin, 1987). Bores 36350 and 36351 (see Fig. 6) have the C subdivision of the *P. tuberculatus* Zone and the *T. bellus* Zone, respectively, at approximately the 130 m level. The *T. bellus* Zone is approximate 15 million years and the *Nothofagus* phase, approximately 5 million years, is found at the 120 m level. There is thus a section missing, the result of erosion and/or non deposition. This pattern is very similar to that of the Lachlan River Valley (Martin 1987). It is thought that this hiatus is the result of lowered sea levels when the

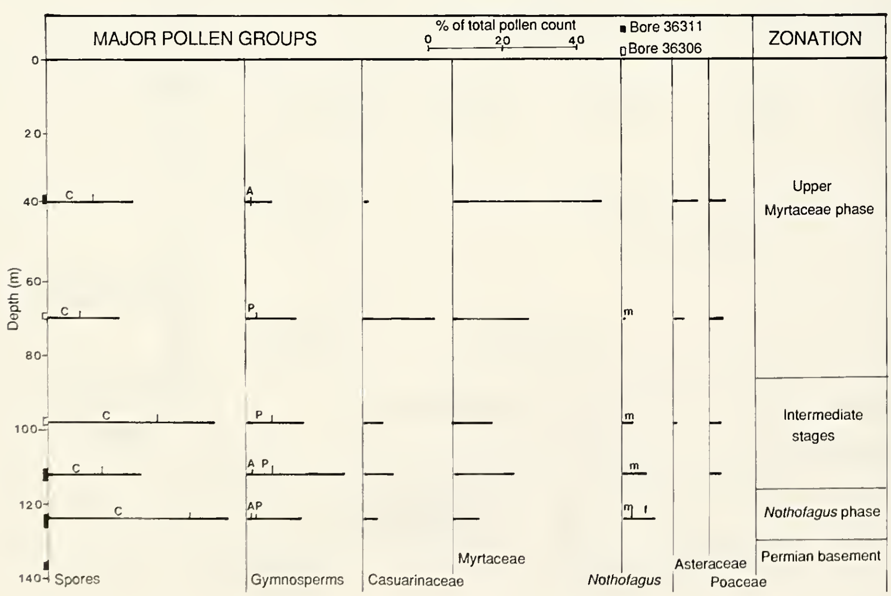

Fig. 9. Composite pollen diagram from two bores. See Fig. 1 for locations. C, *Cyathea*. A, Araucariaceae. P, *Podocarpus* type. m, *menziesii* type. f, *fusca* type.

rivers cut down and the sediment was transported out of the valleys. Haq *et al.* (1987) show that the low sea level stage in the late Miocene at approximately 10 million years was the lowest for the Tertiary.

The late Miocene-Pliocene sequence is similar to that seen in the other river valleys of the western slopes of the Eastern Highlands (Martin, 1987; 1991). The *Nothofagus* phase, if present, is an excellent marker horizon. It occurs near the base of the alluvial fill, but not directly above the basement. The lower Myrtaceae phase beneath the *Nothofagus* phase is not common.

The expression of the *Nothofagus* phase is variable. Here in the Murray River Valley it is a more diffuse horizon. In the Lachlan River Valley, the well defined horizon with *Nothofagus* frequencies decreasing with distance downstream, suggests a migration of *Nothofagus* down the valley from refugia in the eastern highlands, during a brief period when the climate was wetter (Martin, 1987). In the Murray River Valley, the highest frequencies of *Nothofagus* at the base of the sequence (124 m level in Fig. 9) indicate the initial migration into the valley, and the lower frequencies higher in the sequence suggest that small stands remained much longer here than in the Lachlan River Valley. This variation is in accord with the geographic difference: the higher/more southerly regions were more suitable for *Nothofagus*.

The upper and lower Myrtaceae phases are similar to those of the Lachlan River Valley (Martin, 1987). The palaeovegetation was most likely a mosaic with some wet sclerophyll forest, i.e. a eucalypt canopy with appreciable ferns, some rainforest taxa (the gymnosperms, Cupaneae, *Quintinia, Symplocos, Tasmannia* and *Gardenia*), and few herbaceous taxa. Dry sclerophyll forest was present also, as shown by *Acacia, Banksia, Dodonaea, Hakea, Micrantheum, Monotoca, Haloragis / Gonocarpus* and *Haloragodendron* (*Stephanocolpites oblatus*). These genera may include some mesophytic species, but they are more prominent in the drier habitats.

In the late Pliocene-Pleistocene, the rainforest element disappears entirely. There are few ferns, gymnosperms are rare or absent, and the shrub/herbaceous element has increased considerably, particularly the Asteraceae (*Tubulifloridites* spp.).

ACKNOWLEDGMENTS

I am indebted to the New South Wales Department of Water Resources for materials and financial assistance. I wish to thank Mr. R.M. Williams, Department of Water Resources, for information and assistance.

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Appendix 1

The Palynological Zonation

Bores arranged W-E, then N-S. For location , see Fig. 1.

Bore and Depth	Palynological Zonation	Age
36558		
168-190 m	B subdivision, *P. tuberculatus* Zone	Mid-late Oligocene
248-266 m	A subdivision, *P. tuberculatus* Zone	Early Oligocene
36582		
119-166 m	B subdivision, *P. tuberculatus* Zone	Mid-late Oligocene
170-171 m	A subdivision, *P. tuberculatus* Zone	Early Oligocene
36587		
143 m	B/C subdivision, *P. tuberculatus* Zone	Late Oligocene-early Miocene
217 m	B subdivision, *P. tuberculatus* Zone	Mid-late Oligocene
235 m	A subdivision, *P. tuberculatus* Zone	Early Oligocene
280 m	Middle *N. asperus* Zone	Late Eocene
36588		
157-173 m	B subdivision, *P. tuberculatus* Zone	Mid-late Oligocene
36585		
132-136.5 m	Upper *N. flemingii* acme, *P.tuberculatus* Zone	Late Oligocene-early Miocene
190-204 m	B subdivision, *P.tuberculatus* Zone	Mid-late Oligocene
208-213 m	Lower *N. flemingii* acme, *P.tuberculatus* Zone	Early Oligocene
222-226.5 m	? Stage 4	Early Permian
36586		
150-196 m	B subdivision, *P. tuberculatus* Zone	Mid-late Oligocene
199-201 m	A subdivision, *P. tuberculatus* Zone	Early Oligocene
209-254 m	Middle *N. asperus* Zone	Late Eocene
36584		
139.5 m	Stage 4a	Early Permian
Oaklands 15		
114.3 m	B subdivision, *P. tuberculatus* Zone	Mid-late Oligocene
166.1 m	Upper stage 5a	Mid Permian
36635		
100-101 m	B subdivision, *P. tuberculatus* Zone	Mid-late Oligocene
100-109 m	A subdivision, *P. tuberculatus* Zone	Early Oligocene
118-119 m	Mid *N. asperus* Zone	Late Eocene
Oaklands 18		
107.1-116.15 m	B subdivision, *P. tuberculatus* Zone	Mid-late Oligocene
Oaklands 5		
218.2 m	Upper stage 5a	Mid Permian
317.0 m	Stage 3b	Early Permian
Oaklands 12		
135.0 m	Stage 3a	Early Permian
Oaklands 4		
212.4 m	Upper stage 5a	Mid Permian
246.9 m	Stage 4a	Early Permian
256.0 m	Stage 3b	Early Permian
Oaklands 2		
272-278.9 m	Upper stage 5a	Mid Permian
Oaklands 16		
257.5-268.2 m	Upper stage 5b	Mid Permian
Oaklands 1		
224.0 m	Lower stage 5b	Early Permian

Oaklands 14		
198.1-235.6 m	Lower stage 5c	Mid Permian
36638		
173-174 m	Stage 3a	Early Permian
Oaklands 11		
98.4 m	?	Mid Permian
103.3-117.6 m	Upper stage 5a	Mid Permian
Oaklands 17		
176.5-179.5 m	Lower stage 5b	Mid Permian
Bore 36356		
81.4-82.9 m	?	Pliocene
Bore 36350		
128.6-130.1 m	Late *P. tuberculatus/T. bellus* Zone	? Mid Miocene
137.8-139.3 m	Stage 3a	Early Permian
145.3 m	?	Early Permian
Oaklands 13		
96.6-98.4 m	Mid *N. asperus* Zone	Late Eocene
Oaklands 7		
90.8 m	Mid *N. asperus* Zone	Late Eocene
110.5 m	Upper stage 4a	Mid Permian
36399		
51-55 m	Lower stage 5a	Mid Permian
Oaklands 6		
107.6 m	Lower stage 5a	Mid Ppermian
118.3	?	Mid Permian
Oaklands 9		
100.6 m	?	Early Permian
Bore 36390		
103.6 m	?	Early Permian
Oaklands 10		
32.9 m	Upper Myrtaceae phase	Pliocene
121.9 m	*Nothofagus* phase	Late Miocene-early Pliocene
Coorabin 2		
63 m	Stage 3b	Early Permian
36351		
101.2-108.8 m	Myrtaceae phase	Late Miocene-Pliocene
127.1-130.1 m	*T. bellus* Zone	Mid Miocene
139.3-146.9 m	Stage 3a	Early Permian
152.4 m	?	Early Permian
36392		
119.5-121.0 m	?	Early Permian
125.6-127.1 m	Stage 3a	Early Permian
130.1-131.7 m	?	Early Permian
36354		
46.3-50.9 m	Upper Myrtaceae phase	Pliocene
92.0-103.6 m	? *Nothofagus* phase	?Late Miocene-early Pliocene
137.8-139.3 m	?	Early Permian
36355		
98.1-110 m	?	Early Permian
39251		
32-34 m	?	? Pleistocene
96-96.3 m	?	Early Permian

Coorabin 1		
86.6-89.9 m	Stage 3a	Early Permian
36352		
99.7-101.2 m	Stage 3a	Early Permian
111.4 m	?	Early Permian
36394		
89-92 m	? *Nothofagus* phase	? Late Miocene–early Pliocene
101.2-102.7 m	Lower Myrtaceae phase	Late Miocene
36311		
37.4-39.2 m	Upper Myrtaceae phase	Pliocene
110.6-124.3 m	*Nothofagus* phase	Late Miocene Pliocene
136.5-138.1 m	?	Early Permian
36306		
68.0-69.5 m	Upper Myrtaceae phase	Pliocene
96.9-98.4 m	*Nothofagus* phase	Late Miocene–early Pliocene
136.5-138.1 m	Lower Myrtaceae phase	Late Miocene
36295		
120.4-121.9 m	*Nothofagus* phase	Late Miocene–early Pliocene
126.5-131.1 m	?	Early Permian
36303		
66.4-69.5 m	?	Pliocene
36281		
42.0-76.0 m	Upper Myrtaceae phase	Pliocene
83.5-88.5 m	*Nothofagus* phase	Late Miocene–early Pliocene
36376		
45-46 m	Upper Myrtaceae phase	Pliocene
101.5 m	*Nothofagus* phase	Late Miocene–early Pliocene
36416		
27.28 m	Asteraceae/Poaceae	Pleistocene
25281		
52.4-61 m	Mytaceae phase	Late Miocene–Pliocene
25357		
53.0-53.6 m	Myrtaceae phase	Late Miocene-Pliocene
30763 Culcairn		
79.5-81 m	Myrtaceae phase	Late Miocene-Pliocene
36292 Holbrook		
45-47.5 m	?	?Pliocene

Appendix 2

Permian spores and Pollen in selected samples.
References where descriptions may be found are as follows: 1. Balme and Hennelly (1956b). 2. Foster (1979). 3. Price (1985). 4. Truswell *et al* (1977). 5. Balme and Hennelly (1956a).

Bore	Coo 1	Oak 4	Oak 4	Oak 4	Oak 7	Oak 11	Oak 14	Oak 16	Oak 0b
Depth (m)	86.6 to 89.9	212.4	246.9	256.0	110.5	103.3 to 117.6	198.1 to 235.6	257.5 to 268.2	283.7
Acanthotriletes (Microbaculisporites) villosus 1,3							+		
A. tereteangulatus 2	+	+							
Alisporites splendens 2							+		
Alisporites sp	+	+		+			+		
Apiculatisporis cornutus 2	+								
Bipartitispores cf. Verrucosisporites trisectus 2									+
Bascanisporites undosus 1						+	+		
Barakarites rotatus 2	+		+	+	+	+			
B. pluriaenus 2							+		
B. scissa 2		+				+	+		
Brevitriletes levis 2	+								
Cannanoropollis cf. C. janakii 2							+		
Calamosporis diversiformis 1		+							
Circulisporis parvus 2									+
Cyadopites follicularis 2	+								
Dictyotriletes aules 2									+
Didecitriletes ericanus 2		+				+		+	+
Dulhuntyispora dulhuntyi 3							+		
D. parvithola 2, 3		+				+		+	
D. stellata 3								+	
Granulatisporites micronodosus 1		+				+		+	
G. quadruplex 2	+								+
Horriditriletes curvibaculosus 2	+								
Indotriradites splendens 2			+		+				
Interradispora versus 3									+
Leiotriletes directus 1	+	+		+		+	+	+	+
Marsupipollenites triradiatus 2	+		+	+		+		+	+
Maculatisporites amplus 2							+		
Mehlisphaeridium cf. M. fibratum 2									+
Micrhystridium sp 2									+
Osmundacidites senectus 2						+		+	
Plicatipollenites gondwanensis 2	+	+	+	+	+			+	+
Potonieisporites sp 4	+				+		+		
Praecolpatites sinuosus 2	+		+		+	+	+	+	
Protohaploxypinus amplus 2									+
P limpidus 2						+			+
P. varius								+	
Protohaploxypinus spp	+	+		+			+	+	
Punctatisporites gretensis 1	+		+	+	+				
Pseudoreticulatispora (Verrucosisporites) pseudoreticulata 2,3	+		+	+	+	+		+	
Scheuringipollenites ovatus 2							+		+
Striatoabieites multistriatus 2	+					+	+		
Secarisporites bullatus 2									+
Striatopodocarpidites spp.						+		+	+
Striapollenites saccatus 2									+
Verrucososporites hamatus 5			+						
Vitreisporites signatus 2							+		+

Appendix 3

Late Eocene-Oligocene spores and pollen in selected bores. References where taxa may be found are as follows: 1, Stover and Partridge (1973). 2, Germerrad *et al.* (1968). 3, Martin (1973a). 4, Harris (1965). 5, Cookson and Pike (1954). 6, Stover and Partridge (1982). 7, Mildenhall and Pocknall (1989).

	Bore 366586						Bore 36558			
Depth (m)	150-151	195-196	199-201	209-211	217-219	253-254	168-173	186-190	248-252	261-266
Spores										
Baculatisporites disconformis 1					+			0.6		
Crassotrilites vanraadshooveni 2							+			
Cyathea paleospora 3	1.3		1.8	0.6		1.3	1.2	6.0	0.6	1.3
Cyatheaceidites annulatus 1						0.7	+	+		
Cyathidites australis 1										0.6
Dictyophyllidites concavus 4				+			0.6			
Gleichenia circinidites 3	1.3		0.6				+	+		0.6
Ischyosporites gremius 1					0.6	0.7				
Klukisporites lachlanensis 3			0.6		0.6					
Laevigatosporites ovatus 3	0.6	0.6					1.2	1.2		
Latrobosporites crassus 4				+	0.6					
Lycopodiumsporites sp.					+			+		
Matonisporites ornamentalis 1								+		
Peromonoletes densus 1										+
P. vellosus 1								0.6		
Polypodiidites sp. 3					+			0.6	0.6	
Rugulatisporites mallatus 1								+	+	1.3
R. trophus 1							+	0.6		
Stereisporites sp. (*Sphagnum*)								0.6		
Todisporites sp. 3							0.6			
Verrucosisporites cristatus 1	0.6	+					0.6	+		
V. kopukuensis 1	0.6	+	0.6		+	0.7		+	0.6	+
Gymnosperms										
Araucariacites australis 3						1.3	1.7	+	0.6	0.6
Cupressaceae 3				0.6						
Dacrycarpites australiensis 3	0.6	4.5	2.3	2.4	6.4	3.3	1.2	3.0	3.1	1.3
'Ephedripites' notensis 3							+			
Lygistepollenites florinii 1	7.6	1.3	2.3	8.6	3.8	4.7	1.7	2.4	2.5	5.1
Microcachryidites antarcticus 3				1.8		2.0		0.6	0.6	0.6
Parvisaccites catastus 1						0.7				
Phyllocladidites mawsonii 1		7.6	17.9	28.8	21.1	15.3	0.6	+	33.5	11.4
P. palaeogenicus 5				0.6			1.2	0.6	0.6	
Podocarpidites spp.	4.4	8.3	4.9	8.0	5.1	4.7	4.6	7.8	2.5	1.9
Trisaccites micropteris 5		0.6	0.6	0.6		1.3		6.6	+	
Angiosperms										
Banksieaeidites elongatus 1	+									
Cunoniaceae, tricolplate form		+		0.6						
Cupanieidites orthoteichus 1						0.7				
Cyperaceae 3								0.6		
Ericipites crassiexinous 1						1.3				
Gephyrapollenites calathus 1			0.6							
Granodiporites nebulosus 1									+	
Haloragacidites harrisii 1	9.5	5.8	6.8	6.1	13.5	11.3	25.6	12.0	6.8	5.1
Ilexpollenites anguloclavatus 1	1.9	1.9	1.2			0.7	0.6	+	+	0.6
Liliacidites spp.	1.3			0.6	0.6	0.7	0.6			
Malvacipollis subtilis/diversus 1		0.6	1.2	2.4	1.9	1.3	0.6		1.2	0.6
Milfordia sp.				0.6						
Myrtaceidites eucalyptoides 3		0.6		0.6				0.6		
M. parvus 3	5.7	2.6	0.6	0.6				3.6	1.2	
Myrtaceae unidentified		2.6	2.3		1.3	0.7	4.1	0.6		0.6
Nothofagidites asperus 1		1.3					2.9	1.2		
N. brachyspinulosus 1		1.6	0.6	1.8	1.9	1.3		1.2		0.6
N. emarcidus 1	42.4	34.0	25.3	11.0	20.5	22.7	20.8	29.3	19.9	30.4
N. falcatus 1		0.6		0.6		1.3	0.6		1.2	1.3
N. flemingii 1	2.5	5.8	3.7	1.8	1.3	3.3	1.2	3.6	3.7	1.9
N. goniatus 1	0.6							+	1.2	

	Bore 366586						Bore 36558			
Depth (m)	150-151	195-196	199-201	209-211	217-219	253-254	168-173	186-190	248-252	261-266
N. incrassatus 1	0.6			2.4	1.3	0.7				
N. vansteenisii	7.6	7.6	13.6	6.7	5.8	6.7	9.9	5.4	10.5	25.3
Perfotricolporites digitatus 2							0.6	+		
Periporopollenites demarcatus 1	3.8	0.6		0.6	2.6	1.3		1.2		1.3
P. vesicus 1				0.6				+		0.6
Polyorificites oblatus 3							1.2			
Proteacidites annularis 1		0.6	2.3	0.6		0.7	2.3		1.2	0.6
P. cf. *beddoesii* 1					0.6					
P. cf. *latrobensis* 1										0.6
P. ivanhoensis 3		1.3	1.8	0.6		0.7	1.2	0.6	+	
P. obscurus 1				1.2	+					
P. cf. *pseudomoides* 1		0.6						+		
P. recavus 1					0.6					
P. rectomarginis 1	1.3	1.3	1.2		0.6	1.3	1.2	0.6	0.6	1.3
P. reticulatus 1				0.6	0.6					
P. stipplatus 1				+						
P. subscabratus 3		0.6							+	
P. tuberculatus 1		0.6				1.3			0.6	
Procteacidites spp					0.6		0.6	+	0.6	0.6
Quinitinapollis psilatispora 7	0.6	+	1.2				0.6	+		0.6
Sparganiaceaepollenites barungensis 3	0.6						2.9	0.6		0.6
S. sphaericus 3								0.6		
Tetracolporites palynius 6	+		0.6			1.3	0.6		+	
Tricolporites cf. *T. angurium* 1			0.6							
T. leuros 1	0.6				0.6				0.6	
T. adelaidensis 6					+			+	0.6	+
T. substriatus/paenestriatus 3, 1				0.6				+		
Triorites magnificus 1				1.8	0.6					
Tricolpate-tricolporates	3.8	5.1	3.1	3.7	5.8	2.7	5.8	7.2	5.0	2.5
Summary										
Spores	3.9	0.6	3.6	0.6	1.8	9.4	4.4	10.2	1.8	4.4
Gymnosperms	12.6	22.3	28.0	51.4	36.4	32.0	11.0	12.3	43.4	20.9
Casuarinaceae	9.5	5.8	6.8	6.1	13.5	11.3	25.6	12.0	6.8	5.1
Myrtaceae	5.7	5.8	2.9	1.2	1.3	0.7	4.1	4.8	1.2	0.6
Nothofagus	51.7	44.5	43.2	24.3	30.8	30.0	35.4	40.7	36.5	59.5
Ratios										
P. mawsonii/gymnosperms		0.34	0.64	0.56	0.59	0.48	0.14	+	0.77	0.54
N. flemingii/ Total *Nothofagus*	0.05	0.13	0.08	0.07	0.42	0.11	0.03	0.09	0.01	0.03
Inferred Age	Mid-late		Early	Late			Mid-late		Early	
	Oligocene			Eocene			Oligocene			

APPENDIX 4

Upper Tertiary and Pleistocene spores and pollen in selected samples. References where descriptions may be found are as follows: 1, Stover and Partridge (1973). 2, Martin (1973a). 3, Cookson and Pike (1954a). 4, Truswell *et al.* (1985). 5, Martin (1973b). 6, Harris (1965). 7, Martin and McMinn (1993). 8, Martin (1993b). 9, Pocknall and Crosbie (1982). 10, Cookson and Pike (1954b).

Bore	Oak 10		36351		36394		36376		36416
Depth (m)	32.9	121.9	101.2	127.1	89.0	101.2	45.0	101.5	27.0
Spores									
Baculatisporites disconformis 1		4.0							
Cyathea paleospora 2	14.5	16.0	13.4	20.0	10.8	13.3	25.0	24.4	0.8
Cyatheacidites annulatus 1		0.8	1.7		2.0			0.8	
Cyathidites sublilis 1								0.8	
Deltoidospora inconspicua 2	8.5	0.8	3.4	0.8	2.0			1.5	
Dictyophyllidites concavus					1.0				
Gleicheniidites circinidites 2		0.8	+	0.8			2.0		
Klukisporites lachlanensis 2		1.6	0.8		1.0	2.8	1.0	2.3	
Matonisporites ornamentalis 1	1.7	1.6		0.8	+	0.9		1.5	
Laevigatosporites ovatus 2	6.0	2.4	2.5	1.7	1.0		1.0	1.5	1.7
Lycopodium sp.	0.8								
Osmundaceae sp 1,2			0.8	1.7					
Polypodiidites sp.	0.8			0.8		9.5		1.5	
Rugulatisporites cf *R. trophus* 1								0.8	
cf. *Pteris* 7					1.0				
Verrucosisporites sp.		0.8			+	0.9			
Gymnosperms									
Araucariacites australis 2		8.8	1.7	0.8	9.8			0.8	
Cupressaceae 2	2.6	0.8		1.7				0.8	
Dacrycarpites australiensis 2	2.6		0.8	0.8	1.0	0.9	3.0	3.0	
Lygistepollenites florinii 1		0.8		0.8			1.0	+	
Microcachryidites antarcticus 1		1.6						1.5	
Phyllocladidites palaeogenicus 3		0.8	5.9	6.7	4.9	0.9	1.0	5.8	
Podocarpidites spp.	0.8	8.0	5.0	4.2	5.9	3.8	4.0	13.0	
Angiosperms									
Acacia myriosporites 2		0.8		+					
Banksieaeidites elongatus 2	0.8						1.0	0.8	
Canthiumidites (Triporopollenites) bellus 1, 9								0.8	
Chenopodipollis chenopodiaceoides 4	0.8				1.0				0.8
Cupanieidites orthoteichus 1				0.8					
Cyperaceae 2	2.6	0.8	2.5		1.0		2.0	1.5	
Dodonaea sphaerica 2	0.8					0.9			
Ericipites sp.			0.8	+	2.0	0.9	1.0	0.8	
Graminidites media 2	1.7		0.8		2.9	0.9		1.5	5.8
Haloragacidites haloragoides 2	0.8	0.8	1.7		1.0	0.9	1.0	+	3.4
H. harrisii (Casuarinaceae) 2	7.7		1.7	5.0	4.9	3.8	14.0	8.4	16.0
Milfordia hypolaenioides 2						0.9			
Monotoca 8					1.0				
Micrantheum spinyspora 2	0.8								3.4
Myrtaceidites eucalyptoides 2	1.7	5.6	2.5	0.8	1.0	8.5	11.0		1.7
M. mesonesus 2	1.7		6.7	1.7	4.9	2.8	2.0		
M. parvus 2	8.5	7.2	9.2	6.7	12.7	5.7			2.5
Myrtaceae unidentified	20.5	10.4	21.8	10.0	8.8	15.2	9.0	2.3	8.4
Myriophyllum 10								0.8	
Nothofagidites asperus 1		12.8	2.5	3.3	6.9			4.6	
N. brachyspinulosus 1				5.8					
N. emarcidus 1				6.7					
Polyporina granulata 2		0.8						0.8	0.8
P. symphyonemoides 1		+							+
Proteacidites cf. *Hakea*					1.0				0.8
P. ivanhoensis 2				3.3					
P. subscaboratus 2							1.0	2.3	0.8
Proteacidites sp.				1.7				0.8	+
Quintinia psilatispora 2						0.9	1.0	1.5	
Stephanocolpites oblatus 2									2.5

Bore	Oak 10		36351		36394		36376		36416
Depth (m)	32.9	121.9	101.2	127.1	89.0	101.2	45.0	101.5	27.0
Symplocoipollenites austellus 1	0.8	0.8	0.8	0.8		0.9		2.3	
Tasmannia (Drimys) tetradites 2	0.8		4.2	4.2	2.9	0.9	12.0	6.1	
cf. *Tricolpites reticulatus* 9, 10									2.5
Tricolporites geranioides 5			0.8						
T. mataurensis 9									8.4
T. pelargonioides 5					1.0	1.9			
Tubulifloridites spp. 2	0.8	1.6	0.8	1.7		18.1	2.0		21.8
Unidentified pollen types	5.9	5.6	6.6	5.8	8.8	2.8	5.0	5.3	17.6
Summary									
Spores	32.5	28.8	22.7	26.7	16.7	27.6	29.0	35.1	2.5
Gymnosperms	6.0	20.8	13.4	15.0	21.5	5.7	9.0	24.4	
Casuarinaceae	7.7		1.7	5.0	4.9	3.8	14.0	8.4	16.0
Myrtaceae	32.5	23.2	40.3	19.2	27.4	32.4	22.0	2.3	12.6
Nothofagus		12.8	2.5	15.8	6.9			4.6	
Asteraceae	0.8	1.6	0.8	1.7		18.1	2.0		21.8
Poaceae	1.7		0.8		2.9	0.9		1.5	5.8
Cyperaceae	2.6	0.8	2.5		1.0		2.0	1.5	
	Plio-cene	?early Pliocene	Late Miocene Pliocene	Mid Miocene	? Pliocene	Late Miocene	Pliocene	?early Pliocene	Pleisto-cene